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Anatomy of Earthworms

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2.1 Body Structure

2.1.1 Earthworm Body

The body of earthworm is muscular tubular (elongated) with numerous external rings which more or less internally correspond segments. On internal and external rings body segments are organized over body system.

2.1.1.1 External Characters

All earthworm species have long elongated tubular body. The tubular body of earthworm is generally circular in section with annuli, which is formed with superficial grooves. This represents typical vermiform body. The close examination shows that shape of body of earthworms is nearly circular squarish or trapezoidal, if cut into section, vary in different species. In some species like an arboreal *Perionyx* spp., their body is dorsoventrally flattened, which is in most live forms of other species.

Body color also varies in different species due to pigments and ranges from typical/rich brown to various hues of red gray and purple. In some, there is some luminence too. In live earthworms, color can help in differentiating habitat, viz., burrowing forms have light pigmentation, while top soil dwellers have darker pigmentation.

Externally the earthworm body has series of circular depressions or furrows called segments or metamers. These tally with internal segmentations too and their numbers, as well, in relation to internal organs which are characteristic in different species.

Mouth is crescentic in shape and lies on the ventral side of a first segment, i.e., peristomium. Shape and placement of prostomium is also characteristic in different species. This first metamere with prostomium is called buccal segment as it does not correspond to internal segmentation. All along metameric segments or mid region are attached chitinous hook like structures called chaetae or setae. These are

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retractile and offer hold in locomotion. Their number, placement, shape, arrangement pattern, and descriptions in relation to characteristic features (the pores) are taxonomic character. There are numerous pores opening out externally. These have been named with functions and location on body and are of taxonomic importance. Most of these are not visible without use of magnifying glass. Various pores are: (1) Dorsal pores located within interseg mental furrows; (2) Nephridial pores which are minute and scattered irregularly over body surface.

2.1.1.2 Digestive System

The digestive system comprises a tubular alimentary canal extending from mouth to anus. Upon their dissection various parts of the digestive system can easily be differentiated, namely buccal chamber/cavity, pharynx, esophagus, crop, gizzard, intestine, and rectum. Mouth is at extreme anterior end (first segment) and opens into a short buccal chamber. At tip of mouth a bulbous lip is attached and is called prostomium whose size, shape, and location vary between different species. So, it is a taxonomic character. In some species like common Indian Earthworm, *Metaphire posthuma* buccal cavity is continuously protruded out to pick food particles. Lining of prostomium and buccal cavity is very receptive as it contains receptor cells. Due to these earthworms can discriminate and show preference to different kinds of food items. Buccal cavity joins a muscular pear-shaped structure known as pharynx. In some species, pharynx can also be turned inside out (evaginated) to accept food particles with help of prostomium. Pharynx is pulled back (evaginated) and food is pushed in alimentary canal. In some species within pharynx, there are pharyngeal glands or salivary glands which produce mucin for lubrication of food. The secretion of mucin perhaps helps in formation of stable soil aggregates excreted as "castings" (feces). It is also believed that mucin also promotes bacterial growth and rate of humification in soil, which is a very important process for maintenance of soil fertility. Pharyngeal glands also produce proteolytic enzymes which convert ingested protein materials to simple absorbable forms for plants, majority of these pass out or excreted as casting. This in turn increases plant absorbable nitrogen content of soil so as the nutrient in available form is present in the rhizosphere for its absorption by plant roots. Pharynx joins a tubular structure called esophagus in which calciferous glands open. These secrete calcium and carbon dioxide. Calcium probably neutralizes contents of alimentary canal making excreted cast alkaline, thereby helps in reduction of acidity of soil (i.e., cast and with use of vermicompost). Posterior end of esophagus is thin-walled in some species it acts as storage organ. This joins gizzard called as crop. Gizzard is a muscular structure which functions as grinding of food substrate. This is with the help of grit particles within food and with internal cuticular epithelium or lining within gizzard, besides muscular contractions, etc. the ingested food is grinded into fine particles. Some species of worms have two gizzards in sequence and others have up to ten gizzards that appear as a beaded muscular tube. These also comprise taxonomic characters. However, some aquatic species do not have crop and gizzard. Gizzard follows tubular canal which has sphincters valves at both end and internally has epithelial folds having

glandular and nonciliated cells. This portion of alimentary canal was named by Kirtisin ghe in 1939 as stomach. In stomach proteolytic enzymes are secreted which digest proteins. In some species, namely common Indian earthworm (*Metaphire* spp.) and in *Eutyphoeus* spp. have calciferous glands also. These show structural variation between species. Many globally acknowledged zoologists work is documented in literature as Charles Darwin opined that functionally secretions of calciferous gland are to neutralize humic acid of decaying leaves that earthworm consume. Robertson disagreed and opined that the function is to excrete extra calcium. While S. Stephenson, Bani Prasad, and K.N. Bahl gave structures of these calciferous glands between 1930–1950. Since then, however, not much has been studied despite curriculum studies of earthworm all over country and rather world over. Stomach follows or joins a thin-walled tubular structure called intestine that ends at body end the anus. The digestion and absorption of ingested food take place in intestine. Structurally intestine has three regions, namely:

(i) Pre-typhlosolar region which has vascular internal folds. In the region after few segments, there are conical outgrowths called intestinal caeca. These, according to Chen and Puh, structurally, caecae have glandular epithelial cell and secrete amylatic enzyme, so these are digestive glands.

(ii) Typhlosolar region is the middle part of intestine and structurally is differentiable with medium longitudinal folds inside the intestine called typhlosole. This structure shows difference in content to its size, shape, and blood supply. In common Indian earthworm, it is more or less rudimentary, while in common European earthworm, *Lumbricus* spp., typhlosole is very well developed and contains chloragogen cells to increase food absorption with increased surface area. Chloragogen cells are either excretory or function as storage cells of nutriments in the absence of liver in earthworms.

(iii) Last part of intestine is known as rectum and contains feces as rounded pellets which are excreted through anus. The excreted feces are known as castings or casts. Collective mass of casts from earthworm culture or decomposable organic wastes are generally called "vermicompost." However, technically cast and vermicompost are differentiable, former being excrement from soil and later being casts from decomposed organic matter. Physiology of digestion in earthworms in many respects is comparable to functions in higher animals. Depending upon feeding habits, dissimilar species have different enzymes for digestion. In most species, enzyme amylase is secreted that digests starch, thereby C/N ratio of substrate is reduced after passing through intestine, the material is converted into readily assimilable form for plants. Other species may have enzymes like diastase which converts starch into sugar. Some have glycogen hydrolising ferment, lipase (for digesting fats), invertase (acting of cane-sugar) and oxidizing ferment-catalase. In some earthworms evidence of presence of cellulase and chitinase have been reported, but are suggested to have been produced by symbiotic bacteria and blood and coelomic fluid to different parts of body.

2.1.1.3 Body Cavity or Coelom

Body structure in worms is comparable to a tube and tube inside has digestive organs or body organs. In between these two is a body cavity called coelom, which is generally filled with a milky fluid called coelomic fluid. The coelom is enclosed on outer side with inner peritoneal lining of body wall. It is covered with peritoneal lining of alimentary canal in the inner side. Coelom is partially or completely divided by muscular partitions called septa which stretch along inter segmental furrows to alimentary canal or organs. Disposition, thickness, position number(s), and attachments to organs are characteristic features of different species. Coelomic septa have apertures with sphincters to control fluid movement. The function of these apertures is to regulate flow of coelomic fluid to different segments of body for making these turgid which helps in locomotion. Coelomic fluid mainly comprises colorless plasma fluid. In this, various types of corpuscles float and it vary in different species. Commonly found corpuscles are amoebocytes, granulocytes, and leucocytes. Amoebocytes are defense cells against parasites and pathogenic cells which are devoured. Granulocytes contain granules that are believed by many scientists as nutritive in function and carry digested granules to various tissues. Liebmann (1942) opined that leucocytes are also modified amoebocytes, so are expected to have some defense function. Biochemically, coelomic fluid is slightly alkaline (pH 7.9) and is at higher osmotic pressure than surrounding water in substrate. On movement of worm, the fluid appears moving forward and backward. It is still not known whether it is only in appearance due to turgidity in segments or actually in process. However, exudation through skin pores does take place. This is believed to protect worm from bacteria and similar pathogens. The fluid exudation also keeps body surface damp and is also believed to help in respiration besides excretory in function. This is also opined to help in formation of stable aggregate in casts, thus stimulates growth of certain bacteria that help in humification of organic matter present in soils. Worldwide common prank in children is sprinkling of common salt over live earthworm to see killing violent contractions and ultimate of worm. This is due to exosmosis of coelomic exudations of fluids which further cause violent contractions leading to ultimate death. In Squirter worm, *Dielymogaster sylvaticus*, body fluids are ejected to a height of 30 cm to avoid predator.

2.1.1.4 Body Wall

The body wall of earthworm is complex as in other animals. Complete description of its body wall would necessitate background of animal morphology. Therefore, to simplify only brief description is being dealt with. Technically, body wall comprises five layers. These are

(i) Cuticle comprising of two fine transparent layers. The color hues on earthworm body are due to stridulations on these layers.
(ii) Epidermis layer is below cuticle layer. Epidermis comprises four types of cells, viz. glandular mucus, albumin, supporting basal and receptor cells. These serve various functions.

(iii) Muscular layer lies below epidermal layer. Muscular layer has two types of muscles, in layers. These are outer ones (circular) and inner ones (longitudinal).

Follicles are present within epidermis, which secrete chitinous setae that protrude outside body. These are placed in single line around periphery of each segment. Structurally setae are fine microscopic, needle like structure. Setae, being chitinous and supported with muscles chiefly serve functions of locomotions. In some species these comprise important taxonomic characters.

2.1.1.5 Locomotion

Setae of earthworms are chiefly locomotory purpose organs. Some setae also play role in copulation. Locomotion in earthworms involves set of synchronized activities from circular and longitudinal muscles, the setae, the septa, and body cavity. In soil when space is available, worm will elongate extending its interior end into the space, grip the surface with setae, expand sideways by contracting longitudinal muscles, and finally pushing aside soil particles from its burrow. Thus by burrowing, burrow formation is affected. If space is not available, viz. there is a non-burrowing object or hardened soil, worm will circumvent such obstacle. On finding palatable material, worm will swallow by gripping it with everted pharynx and swallowing with retraction of pharynx. Due to this activity, many refer locomotion and burrowing as 'worms cats its way'. Occasionally even in language, process is referred as proverb, viz. eating like a worm or eating its way through.

Respiration: Respiration in earthworms is simple but very efficient. Terrestrial earthworms do not have any specialized organs for respiration; however, some aquatic worms have gill like organs. In the majority of worm species, respiration is through skin, i.e., body wall having plentiful blood supply. Body wall is kept moist by mucus glands, oozing coelomic fluids through dorsal pores, nephridial excretions, and also the ground moisture. The exchange of carbon dioxide with oxygen is done through permeable body wall epidermis and blood capillary network having respiratory pigment, the hemoglobin which transports exchanged and dissolved oxygen to different parts through blood vessels. This oxygenation or respiration occurs both at low oxygen pressure, as well as at high pressure from air. But the efficient respiration takes place when skin is moist. The earthworms can live under low levels of oxygen for 6–30 h. That is why the earthworms survive when they are buried in soil.

2.1.1.6 Excretion

Excretion processes are brought about by various developed body functions. Main organs for excretion are tubular structures called Nephridia, present in different body segments within coelom. Their numbers, shapes, sizes, and location considerably vary between species and in some these help in identification. In most species, broadly structure of nephridia comprises a funnel shaped structure with ciliated cells called nephrostome which lies in the segment preceding to one occupying main body of nephridia. Nephrostome or nephridiostome is linked to a small tube

which joins the convoluted mass. The body of nephridia remains attached with tissues. According to excretory action: outside (exonephric) or inside (enteronephric), nephridia are named. Also, according to location within body, nephridia are named, viz. septal (on septum), integumentary (on integument), and pharyngeal (on pharynx). Nephridia also differ in sizes, viz. large (meganephridia) and small (micronephridia).

The excretory functions begin with nitrogenous wastes from different organs and systems that are diffused in coelomic fluid, getting into nephrostomes. The ciliated funnel of nephrostome allows only preferred entry of materials. The fluids then pass through canals of nephridia which with selective absorption extract water and other useful materials, but allows passage of only nitrogenous wastes. These materials like urea, ammonia, and amino acids, besides some comprise other materials like creatinine. These pass out through nephridiopores. In nephridia that are devoid of nephrostomes, wastes are directly absorbed by body of nephridia and passed out of nephridiopores or are transferred into gut. Enteronephric nephridia are perhaps adaptive features for preservation of water within worm body. Exonephric nephridia excrete wastes to exterior through nephridiopores as urine. Urine binds soil particles and forms stable aggregates of soil, stimulating microbial growth for humification or organic matter. Several other excretory mechanisms are working in earthworms. Certain unique cells called chloragogen cells present in the coelomic epithelium of intestines are important in removal of excretory materials from blood. These acts like a mobile liver to maintain required levels of certain substances in blood and coelomic fluid. In *Eutyphoeus* spp. even hepatopancreatic glands have been reported. Other excretory cells are uric or bactericidal cells which also function like amoebocytes. Therefore, nephridia remain as most important excretory organs, functioning like kidney of higher vertebrates, performing functions of excretion, filtration, reabsorption and chemical transformation.

2.1.1.7 Circulatory System

Blood of earthworms is peculiar to its life activities. The blood plasma or fluid of worms is red colored because of dissolved hemoglobin (the transporter and absorber of oxygen) while corpuscles suspended in the fluid are colorless and are nucleated. The hemoglobin gets saturated with oxygen to as high as 95% (in form of oxyhemoglobin) and gets unloaded with transfer of oxygen to different organs in blood circulation process, e.g., in respiratory physiological process that continues even at lower (generally above 19 mm) oxygen pressure. Thus, earthworm hemoglobin functions efficiently both at saturation point, as well at low environmental oxygen levels. These qualities surpass even so advanced creatures like *Homo sapiens*, the man, whose hemoglobin at a level below oxygen saturation point, would "drown in oxygen," i.e., succumb. Further man cannot easily survive in prolonged low or high levels of oxygen; however, earthworms can survive. The blood vessel system in earthworms is complex as in higher animals. It has been divided into three parts, viz. in the region of intestine, in first 13 body segments, and circulation course of blood.

The circulatory system of earthworm comprises three principal blood vessels, namely dorsal vessel, sub-neural vessel, and ventral vessel. The dorsal vessel runs

along the upper midline of the gut and it is the main blood collecting vessel. Blood is moved in forward directions by contractile actions of dorsal vessel. Lying close to nerve chord is sub-neural vessel. Some earthworm species do not have sub-neural vessel, while most (except *Megascolecidae* species) have two such vessels. Its branches collect blood from anterior tissues and organs and return it to dorsal vessels by dorso-sub-neural vessel which run in the septa of each segment. The ventral vessel supplies blood to organs, including skin. In this vessel, blood flows anteriorly to posteriorly. By neural and sub-neural vessels, blood is collected and passed on to dorsal vessel. Pumping of most of the blood from dorsal vessel is into ventral vessel by several (3, 4 or 5 nos.) pairs muscular hearts with valves surrounding esophagus. The flow of blood is unidirectional. The blood this way distributes digested nutrients from food to various regions of body and collect waste materials which pass out to nephridias, coelomic fluid, and to skin. From capillaries of skin, hemoglobin carries the absorbed oxygen to various other tissues.

2.1.1.8 Nervous System

The nervous system of earthworms consists of brain which is in form of fused ganglia lying dorsal to pharynx and it is called as supra-pharyngeal ganglia. From their brain, a pair of circumpharyngeal connective arises, which encircles pharynx and ventrally joins with a pair of sub-pharyngeal ganglia. From ganglia, starts nerve chord that runs up to posterior end. On nerve chord are swellings, i.e., ganglion which give off nerves to various structures within segments. These nerves have both sensory and motor fibers. Sensory fibers provide stimuli to nerve chord and stimulus is transferred to motor fiber going to muscles affecting them contract. In the epidermis of earthworms, at places, localized nerve cells are present in the form of receptors. These are of different kinds. Epidermal receptors are sensitive to touch and also perceive thermal and chemical stimuli. Buccal receptors are found in the epithelium of buccal cavity. These receptors can perhaps smell and taste food. The earthworms are able to differentiate their food items due to these receptors. Photoreceptors are mainly concentrated on prostomium and first body segment. Because of these, the earthworms negatively respond to strong lights and somewhat positively to weak lights. These explain process of retraction of worms during bright days and their emergence during nights. However, these responses vary in different species. There are some earthworm species that emerge only during night like African Night Crawlers, the *Eudrilus* spp. Interestingly, it is reported that in Canada, collection of *Lumbricus terrestris* during night (through Flash lights) is widely done. So, collected earthworms are exported to USA for use as fish baits. It is time that developing countries start paying more attention to such aspects.

2.1.1.9 Reproductive System

Earthworms are hermaphrodite having ovaries and testes in same individual. Mostly cross fertilization occurs in earthworms due to relative positions of male and female genital apertures. Earthworms are protandrous, i.e., male sex cells ripen much earlier than female cells. Therefore, self-fertilization is prevented.

(i) The male sex organs consist of two bag like sacs comprising testes that produce spermatogonia (immature sex cells). Spermatogonia are shed in testes sacs and transfer to seminal vesicles where these undergo further maturation and form spermatozoa (mature male reproductive cells), pass through funnel shaped structure to vas deferens (tube-like structure), and finally are discharged to exterior through male genital pores located on ventral side. Position of male genital pores varies in different species, so the character is of taxonomic importance.
(ii) The female sex organs consist of ovaries, in which egg cells are produced. Ovarian funnel is located below ovaries that lead to tubular oviduct opening to exterior through female genital pores located on ventral side.

Besides, male and female organs, there are paired organs called spermatheca in which sperms flowing from other partners are stored and are nourished by some fluids.

2.1.1.10 Reproduction and Cocoon Formation

Fertilization as a rule in earthworms is cross fertilization, i.e., eggs of one individual are fertilized by sperms of other individual. For this exchange process copulation takes place in which two individuals lie opposed to each in head to tail position with spermathecal pores, closely addressed to each other pores. Each copulating individual move sequentially till all sperms are discharged into spermathecae. This process is also referred by some as charging of spermathecae. Copulatory activities differ in some species as in some earthworm species, the male sex pores are raised to form papillae with a cup like attachment. The prostatic duct (sperm duct) like structure is evaginated to form a penial structure that is inserted for direct transmission of sperms. Separation of copulating individuals succeed changes in clitellum which gradually gets covered with a mucilage. This process follows release of ovum by individuals within mucilage cover and comprises the stage when fertilization takes place with simultaneous release of sperms. In some species, fertilization within mucilage cover occurs when copulating individuals retract backward from the albuminous mucilage rings. In some, it is after separation. However, fertilization from single individual is also reported in some species, viz. *Dichogaster bolaui*. After fertilization, the cocoon or the egg capsule is formed from clitellar gland which is having three layers and is believed to be made from some kind of chitinous material and also has proteins. This is actually formed in most species when individual worm retracts out from the albuminous mucilage ring over its clitellum. This contains albumen and outer covering gradually hardens on exposure to air.

Shape of cocoon: The shape of cocoons in general is ovoid. Freshly laid cocoons are whitish or dull white, soft, and jelly like. In most species, cocoons are laid on surface of substrate when temperature (for embryo development) and moisture are favorable.

Season: In most parts of India, viz. in common earthworm, *Metaphire posthuma*, cocoons are laid from April to October with peaks between August and October months. In *Drawida bolaui*, peak cocoon laying 5000/m^2 has been reported during mid-September with earthworm population of 1150/m^2 individuals. All these

indicate reproductive activity, i.e., survival of juveniles in summers. The vermiculturists/farmers should periodically monitor these earthworms in their culture troughs or beds. The information so generated will enable vermiculturist maintain profitable culture and eventually better compost productions from material under use.

2.1.2 Shape, Size, and Color of Cocoons

Color: The color variations vary from yellowish brownish to greenish brown. However, in some species, these are milky white like pearls.

Shape and size: The shape of cocoons is mostly coriander seed shaped with both tapering ends. But these vary and in *Criodrilus* spp. ornamentations on spindle shaped structures (are reported by Prof. B.K. Senapati) are long (1.5–7 cm) corresponding to length of clitellum. Size of cocoons also varies between species. Professors B.K. Senapati and S.K. Sahu have studied in detail on 15 temperate and tropical species, respectively, range as follows:

Temperate species: have dry weight (mg) 0.86–12.0 mg; diameter 1.3–3.7 mm and length 2.0–6.9 mm. In most commonly used species, *Eisenia foetida*, dry weight is 3.7 mg; diameter 2.9 mm and length 6.0 mm.

Tropical species: have dry weight 0.65–32.60 mg; diameter 1.0–9.0 mm and length 2.0–15.0 mm. Cocoons of world's largest earthworm of Australia, *Megascolides australis* has diameter of 20 mm and length of 75 mm. It contains single embryo which on emergence measures nearly 30 cm s, i.e., 1 ft.

Temperature and moisture level for cocoon production: The production of cocoons and its survival is important for further progeny. These are dependent upon several factors. In general, optimal conditions are at substrate temperature range between 15 and 25 °C (depending upon species, design of the vermiculture container, and weather control measures like shade), with 20–40% moisture in substrate, i.e., 60–100% air humidity, ionic conductivity below 3 m mhos/cm darkened environment. Feed substrate preparation is essential step and should not have any contamination with lethally toxic chemicals.

Survival rate: In each cocoon, number of eggs may range high. However, survival is only in one or two or three. Production of cocoons with favorable conditions is throughout the year. During colder months, less number is produced than in warmer months, so cannot be generalized for reproduction rates (cocoon production as indicator) of various species in different regions. Prof. B.K. Senapati and S.K. Sahu have reported annual cocoon production per adult/year in 15 temperate and 15 tropical species. These corresponding values range between 8.00 and 92.00. and 1.30 and 46.59per adult/year, respectively. The earthworm species, *E. foetida* have an average of 17 cocoon production per adult/year. When two individuals mate at a time and release their individual cocoons, then cocoon production is actually double the number.

Incubation period: Incubation period ranges 3–30 weeks in temperate species and 3–8 weeks in tropical species. The incubation period of two common earthworms species widely used in Vermiculture, namely *Eisenia foetida* is 3–4 weeks

and *Eudrilus eugeniae* is 2–3 weeks, respectively. However, their further development also depends upon temperature, moisture, and substrate conditions. On an average, young ones grow to maturity in 2–13 months. In vermiculture, preference is given to those species which have higher rate of reproduction, quick maturity, and faster development, besides other parameters. The African species which are widely used for vermiculture have characters, viz. freshly emerged individuals have rapid growth and attain reproductive stage (develop, clitellum) within 6 weeks and cocoon laying continues for 3–6 months when gradually number decreases. The earthworms then can be harvested for other purposes.

Environmental conditions and soil pH: Under natural conditions, reproductive potential and other activities of earthworms depend upon some important factors, viz. environmental conditions and soil pH. Most earthworms prefer neutral soils. *Eisenia foetida*, common sewage worm, prefers alkaline soils and some others prefer or tolerate slightly acidic soils.

Moisture conditions: Moisture conditions of soil as well that of worm body influence its distribution, viz. vertical distribution to soil surface when availability of leaf litter is more. So better growth and soil conditioning is expected unless humus is available in lower reaches (for example, in pits). Under decreased moisture conditions, worms go in deeper layers and may undergo diapause.

Temperature: The temperature has also direct bearings to reproduction and distribution, etc., as affects various activities like metabolism, respiration, growth, reproduction, production, and hatching of cocoons. Temperature tolerance range is different for various species. Extremes of temperature range limit tolerances and activities.

Types of soils: Types of soils also determines the total biomass of worms to be supported. In general, light and medium loam soils have more worms than heavier clays and alluvial soils.

Kind of food: The kind and amount of food influences their type, number growth, and fecundity. Other factors related to worm reproduction and distribution are feed and its availability. Earthworms produce more cocoons when these are fed on decaying organic matter or on nitrogen-rich diets. Among vegetable matter, leaf litter is most preferred. Many species are reported to possess capability to discriminate leaf litter according to shape, mineral, alkaloid, and protein contents. With careful observations, it is simple to make out suitability of leaf litter or other organic material for earthworm propagation.